Program Overview:
Engineering & Systems Design (ESD)
Systems Science (SYS)

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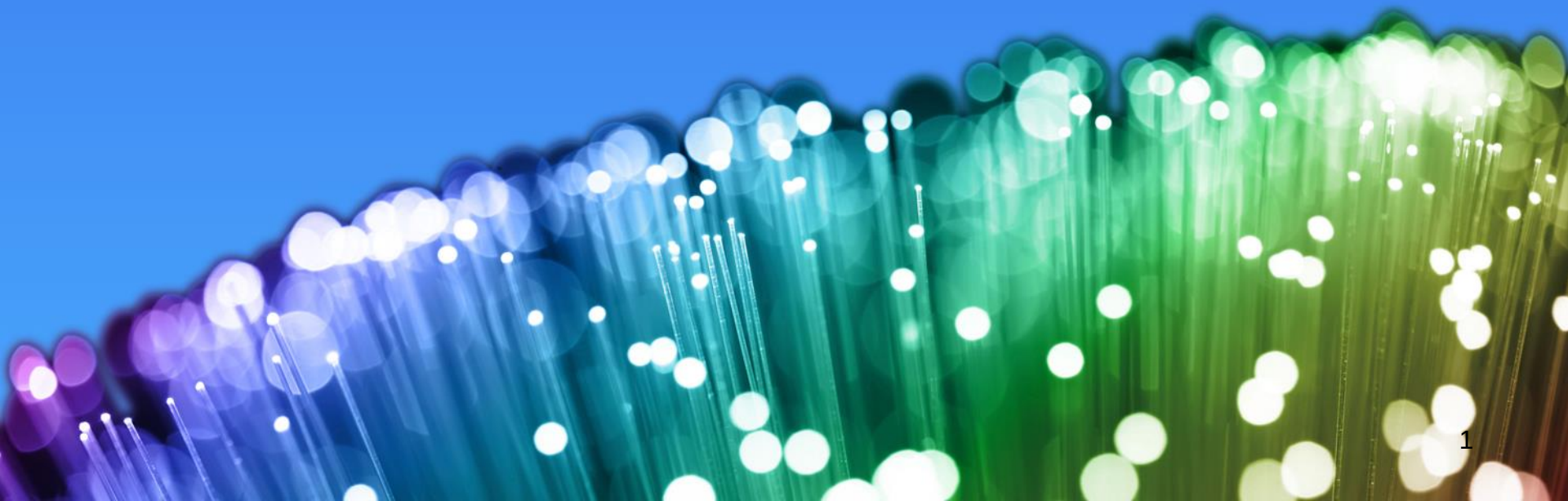
Chris Paredis
Program Director
NSF ENG/CMMI Engineering & Systems Design, Systems Science
cparedis@nsf.gov
(703) 292-2241



Disclaimer

- Any opinions, findings, and conclusions or recommendations expressed in these slides are those of the author/presenter and do not necessarily reflect the views of the National Science Foundation.

- In October 2015, this presentation was recorded. The video is available at http://tinyurl.com/ESD-SYS

Outline

- Context
  - Where do the programs fit in the context of NSF?
  - A Story of Design… My conceptual framework for systems engineering and design
  - Why a shift towards systems?
  - The difference between Systems Engineering and Engineering Design
- Systems Science
  - Program details, research examples, and future directions
- Engineering and Systems Design
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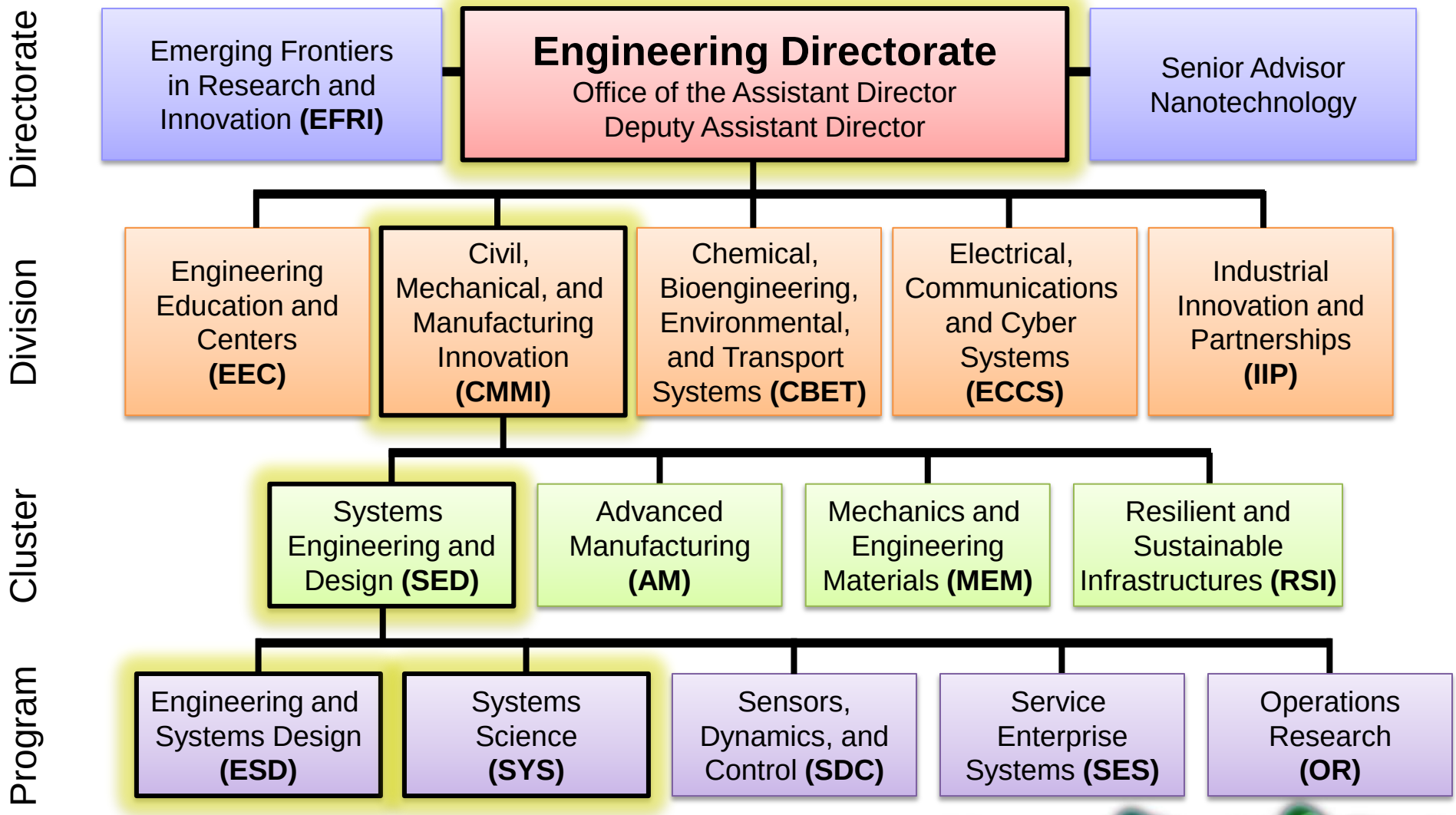
- Discussion

Where Do ESD and SYS Fit In?



A Story of Design…

Maybe a Step Towards a Common Understanding

- Why do designers design artifacts?

  because it adds value…**to the designer**

1. Individual designer — artifact for personal use
   - Designer obtains added value directly from artifact use
2. Individual designer — artifact for sale
   - Trading → consumer surplus + producer surplus
   - Through trading, both consumer and producer benefit
3. Designer in firm — artifact for sale
   - Producer surplus received by firm → firm pays designer's salary
   - Organizing in firms is beneficial because it reduces transaction costs

What do we Mean by Value?

Value is an Expression of the Preferences of the Designer

- Value is an expression of preference – the more an outcome is preferred, the higher the value assigned to it
  - A philanthropist may assign high value to an alternative that significantly increases well-being even if it cannot be produced at a profit
  - An environmentalist may assign high value to environmentally friendly, sustainable alternatives
  - A publicly traded company may assign high value to profitable alternatives
- Value is often expressed in monetary terms
  - If a designer prefers outcome A over outcome B then he/she is willing to exchange A for B plus a dollar amount of $\Delta v = v_A - v_B$

Designing To Improve the Lives of Others

… But Benefiting the Designer in the Process

1. Understand the customers — How could their lives be improved?
2. Identify value opportunities — Where can the firm add value by creating something new?
3. Design a new artifact — A valuable artifact that can be produced for less than what the customer is willing to pay
4. Sell the artifact to the customer — The firm and the customer are better off by receiving a portion of the added value
5. Get paid by the firm — A long-term relationship between the designer and the firm is more valuable than carrying the market transaction costs each time

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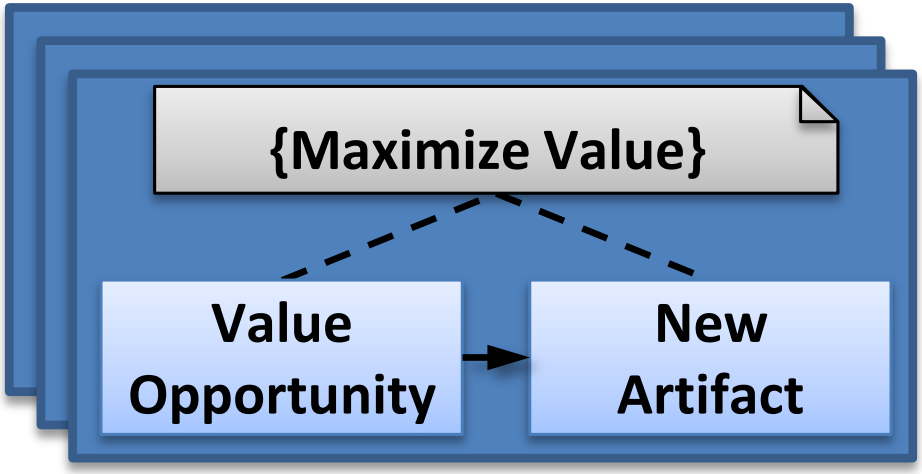
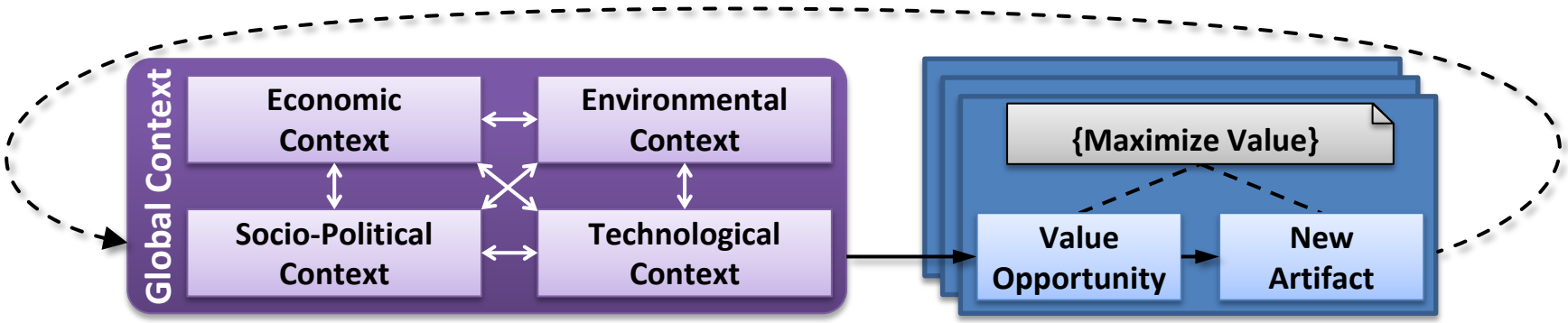
Designing, Trading, Organizing in Firms…
Add Value… **to the designer**… and to others.

SE & Design: Maximizing Value



SE & Design: Maximizing Value

Value Opportunities in a Global Context



SE & Design: Maximizing Value

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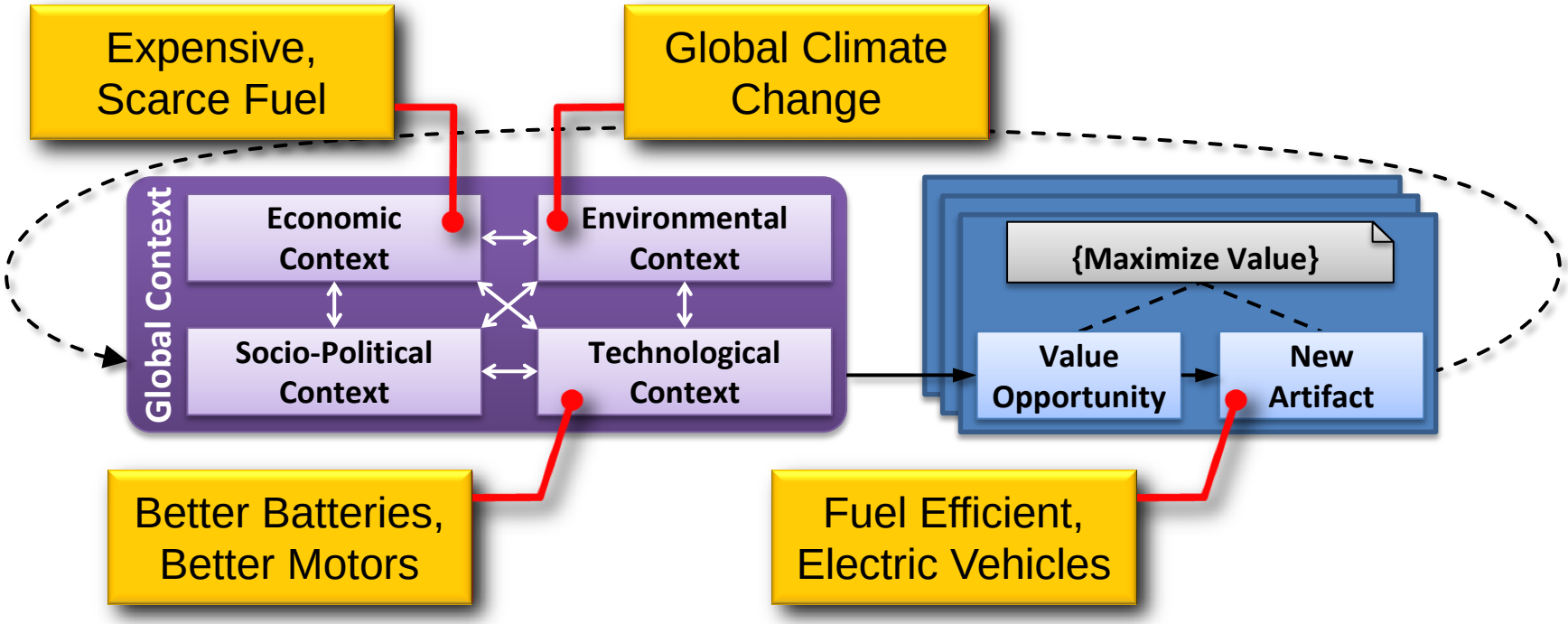
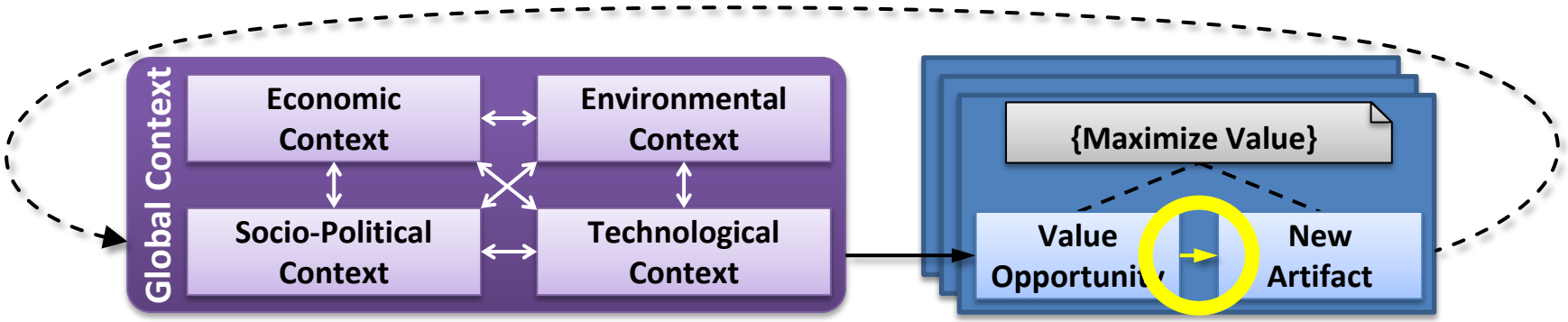


SE & Design: Maximizing Value

Value Opportunities are Restricted by SE&D Capabilities



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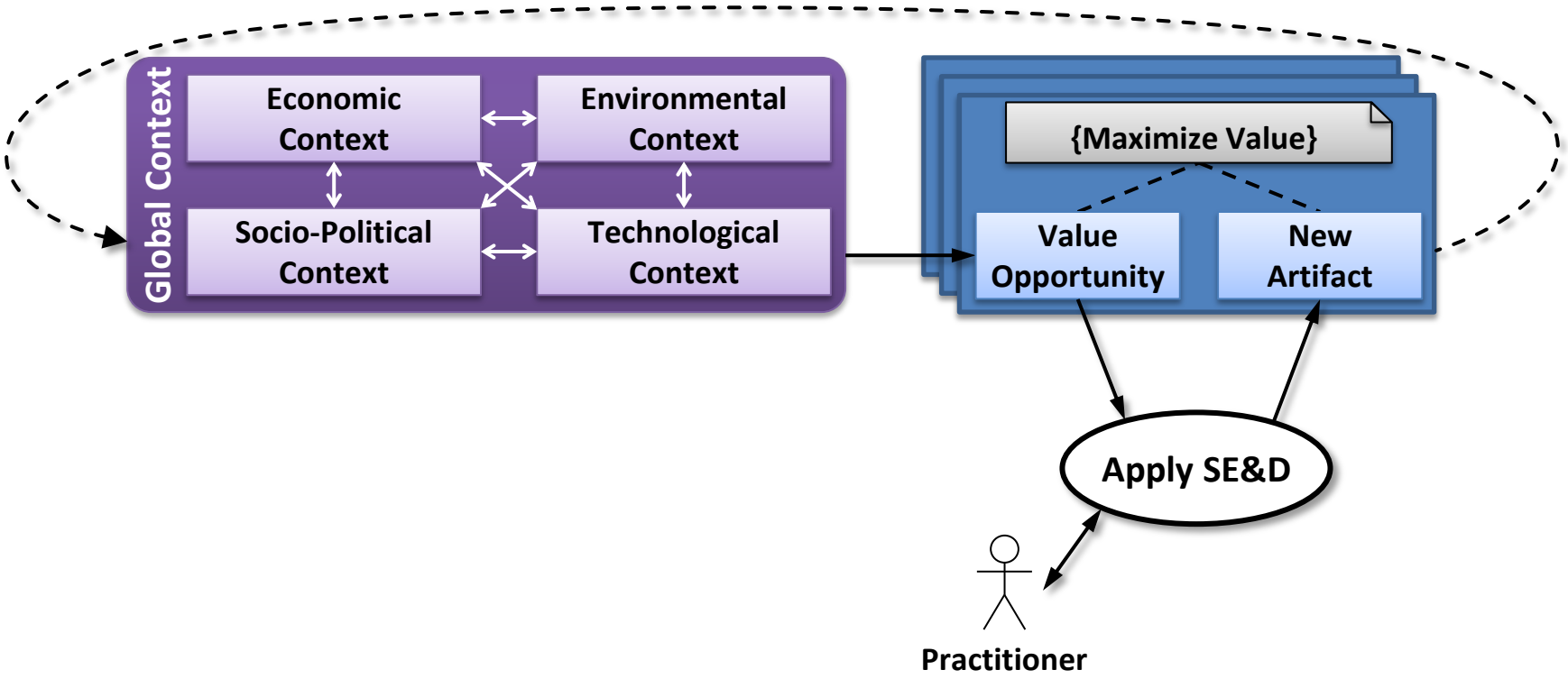
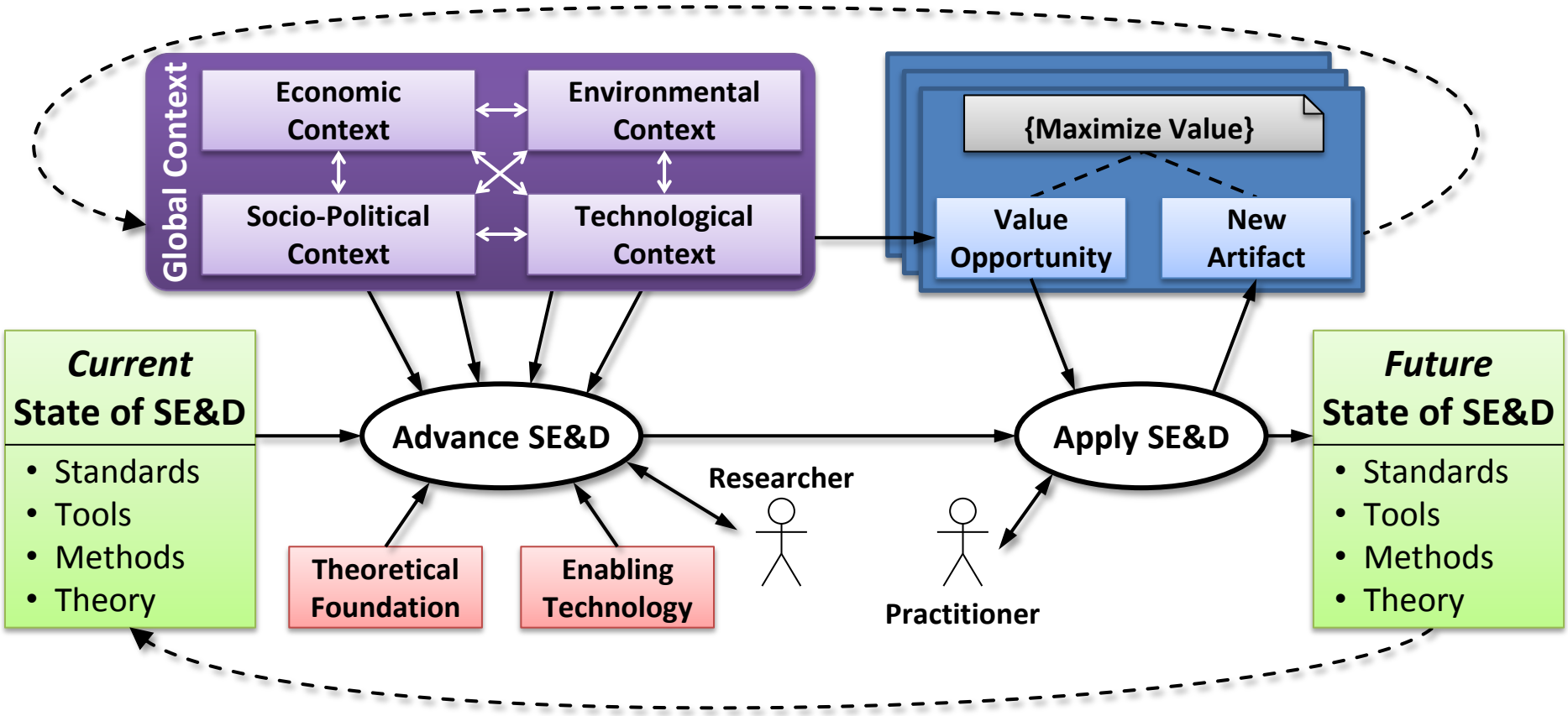


SE & Design: Maximizing Value

Value Maximization Drives Advances in SE&D



SE & Design: A Search Strategy

Value of the Artifact…

- Maximizing the value π_A of an artifact a:

$$\mathcal{A}: \max_{a \in A} \pi_A(a) \longrightarrow$$ Overlooks importance of uncertainty…

$$\mathcal{A}: \max_{a \in A} \mathrm{E}[u(\pi_A(a))] \longrightarrow$$ Overlooks importance of the search process…

SE & Design: A Search Strategy

Value of the Artifact minus Development Cost

- Maximizing the value π_A of an artifact a:

$$\mathcal{A}: \max_{a \in A} \pi_A(a) \longrightarrow$$ Overlooks importance of uncertainty…

$$\mathcal{A}: \max_{a \in A} \mathrm{E}[u(\pi_A(a))] \longrightarrow$$ Overlooks importance of the search process…

- The search process requires time and resources:

$$\mathcal{A}: \max_{a \in A} \mathrm{E}\left[u\left(\pi_A\left(a, t(\mathcal{A})\right) - C(\mathcal{A})\right)\right]$$

SE & Design: A Search Strategy

Value of the Artifact minus Development Cost

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- The search process requires time and resources:
  → Self Reference!

$$\mathcal{A}: \max_{a \in A} \mathrm{E}\left[u\left(\pi_A\left(a, t(\mathcal{A})\right) - C(\mathcal{A})\right)\right]$$

- Leads to infinite planning regress
  → heuristics are required

SE & Design: A Search Strategy

Artifact is the Outcome of a Process

- Maximizing the value π_A of an artifact that results from a process p:

$$\mathcal{P}: \max_{p \in P} \mathrm{E}\left[u\left(\pi_A\left(a(p), t_p(p)\right) - C_p(p)\right)\right]$$

- No longer self-referential, but still dynamic in the sense that future process steps depend on the outcomes of previous process steps
- Search strategy, p, and resulting artifact are inextricably linked

→ Must make a tradeoff between artifact value and search time & cost

SE & Design: A Search Strategy

Search Process is Performed by an Organization

- Maximizing the value π_A of an artifact that results from a process p, performed by and organization o:

$$\mathcal{O}: \max_{\substack{o \in O \\ p \in P}} \mathrm{E}\left[u\left(\pi_A\left(a(p,o), t_p(p,o)\right) - \sum_{i(o)} C_o(p,o)\right)\right]$$

- Socio-technical problem
- Should build on organizational sociology, game theory, mechanism design,…

→ A crucial part of systems engineering and design is the choice of search strategy and organizational structure

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Where do SYS and ESD fit in?

Why a Shift Towards Systems?

Engineering Design & Innovation (EDI) → ESD & SYS

"The EDI program supports research leading to design theory and to tools and methods that enable implementation of the principles of design theory in the practice of design across the full spectrum of engineered products."

Complex Engineered Systems

- Multiple disciplines
- Multiple stakeholders
- Multiple concerns
- Complex interactions
- Uncertain outcomes

- Explicit focus on a Holistic, Systems Perspective
- We can no longer limit ourselves to just a mechanical engineering perspective

→ Unless we adapt, we become irrelevant

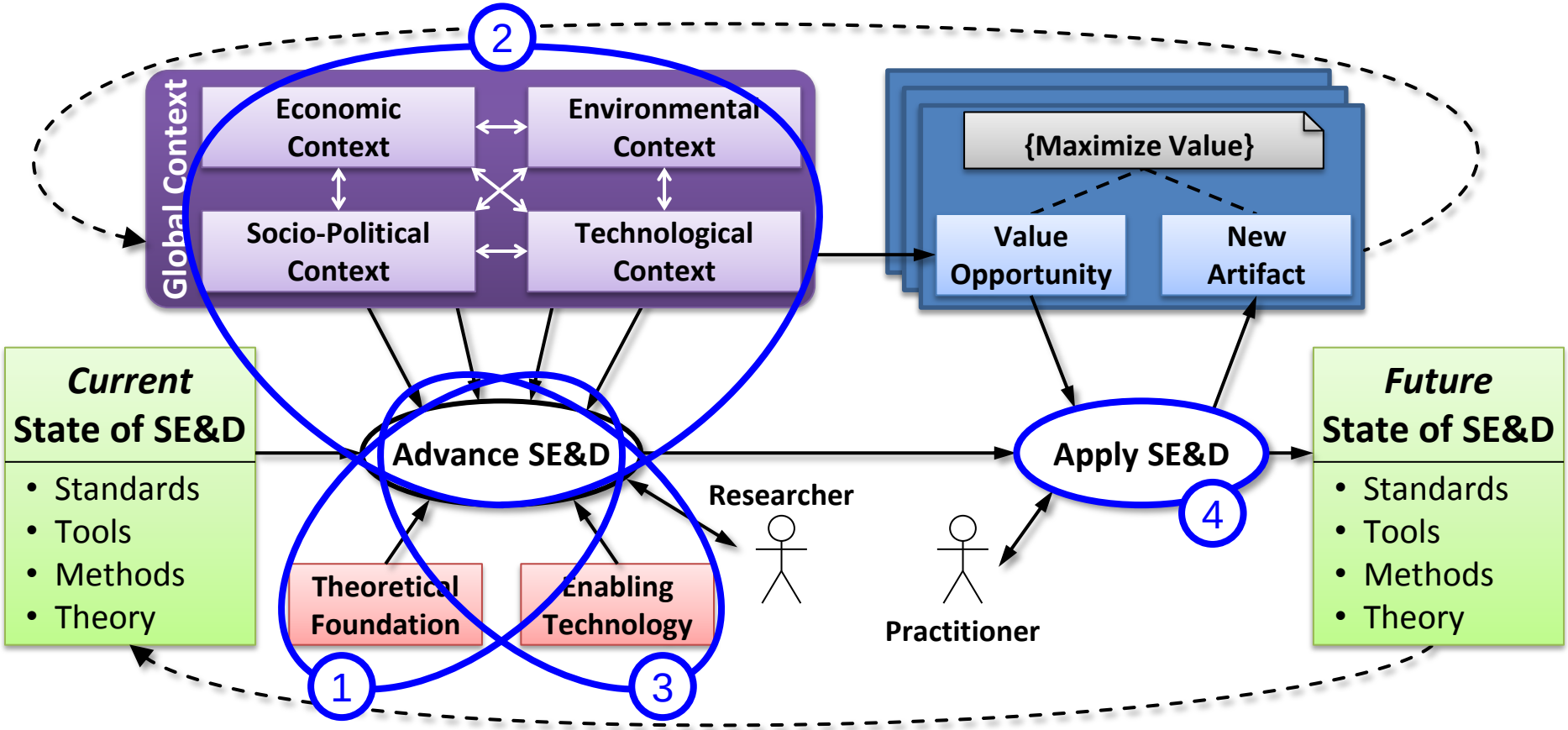
Engineering Design ↔ Systems Engineering

Relative Importance of Artifact vs. Process & Organization

- Engineering Design
  - Artifact-focused
  - Later in development process
  - Applies to relatively simple systems or components
- Systems Engineering
  - Process and organization-focused
  - Early in development process
  - Applies to more complex systems
- Distinction is somewhat artificial — communities would benefit from more interaction

SE & Design: Maximizing Value

Value Maximization Drives Advances in SE&D



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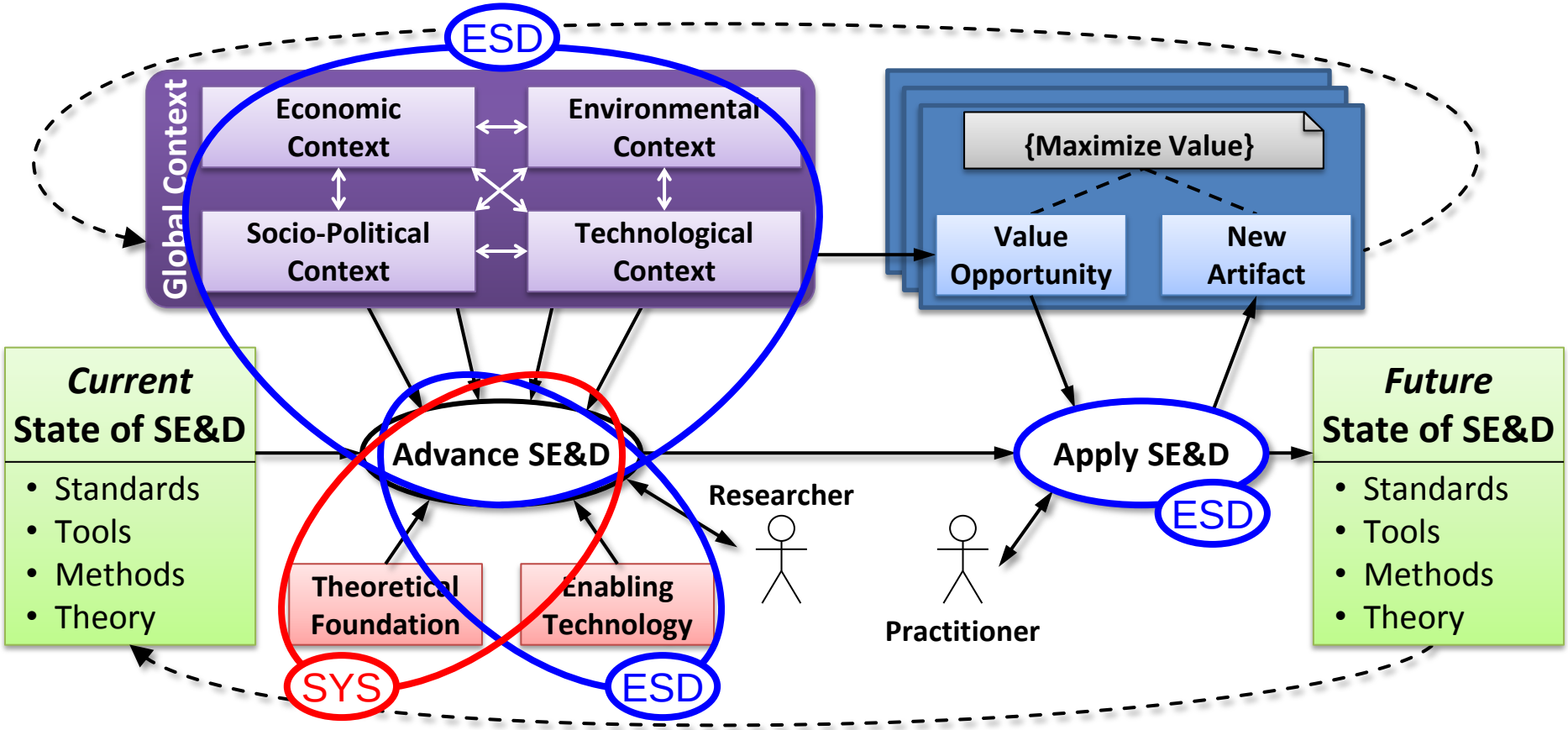

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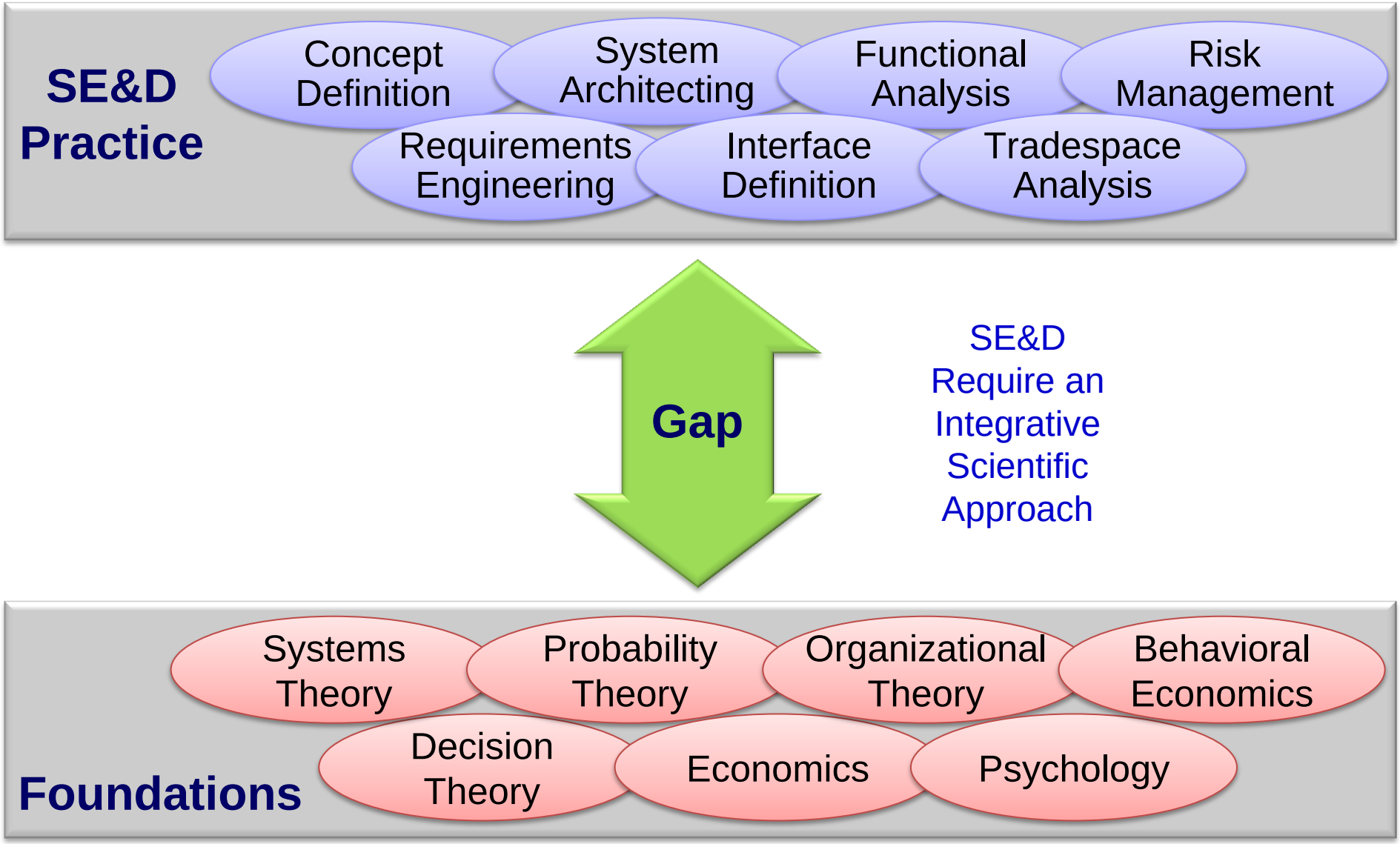
Systems Science (SYS)

Theoretical Foundation for SE & Design



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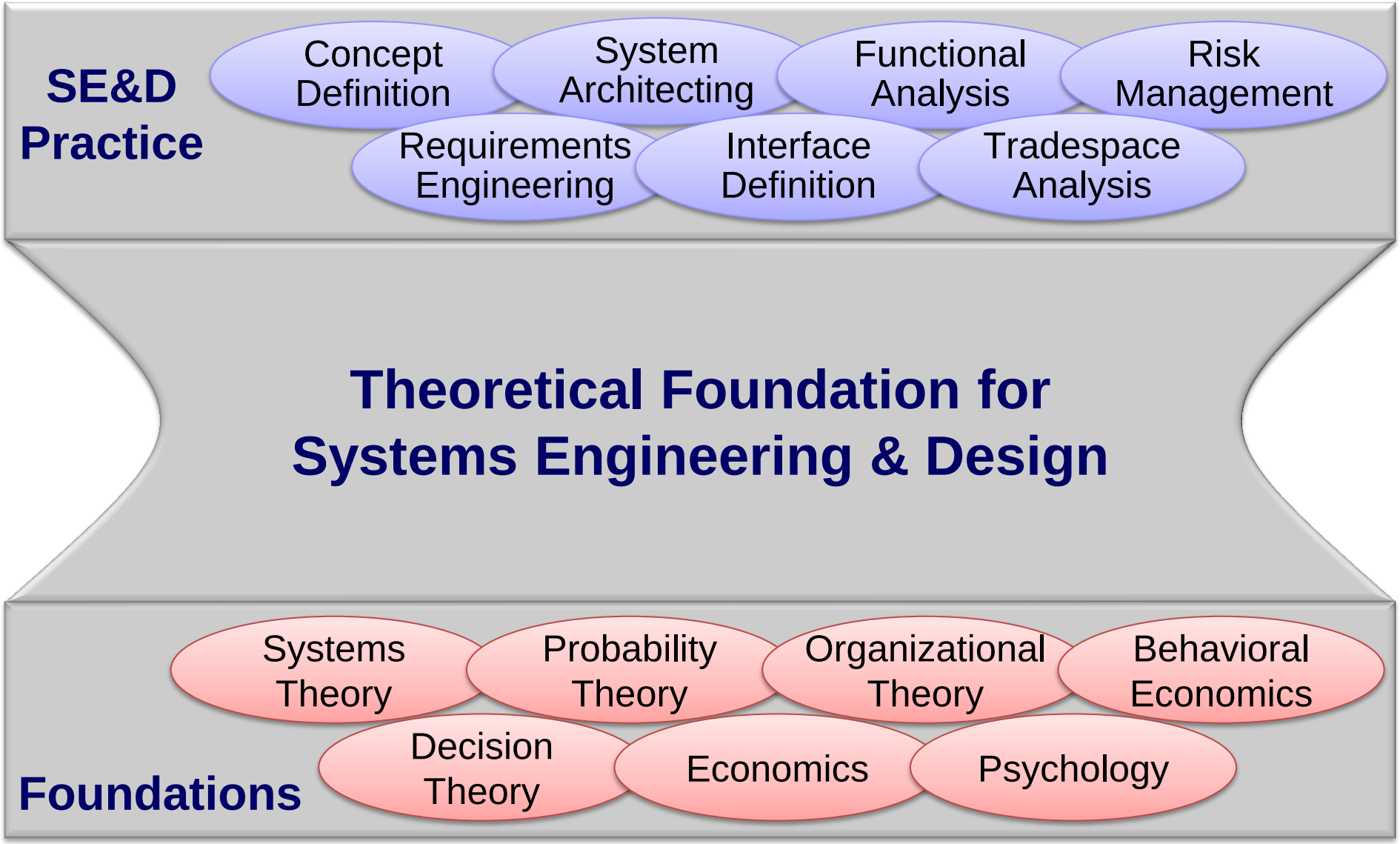

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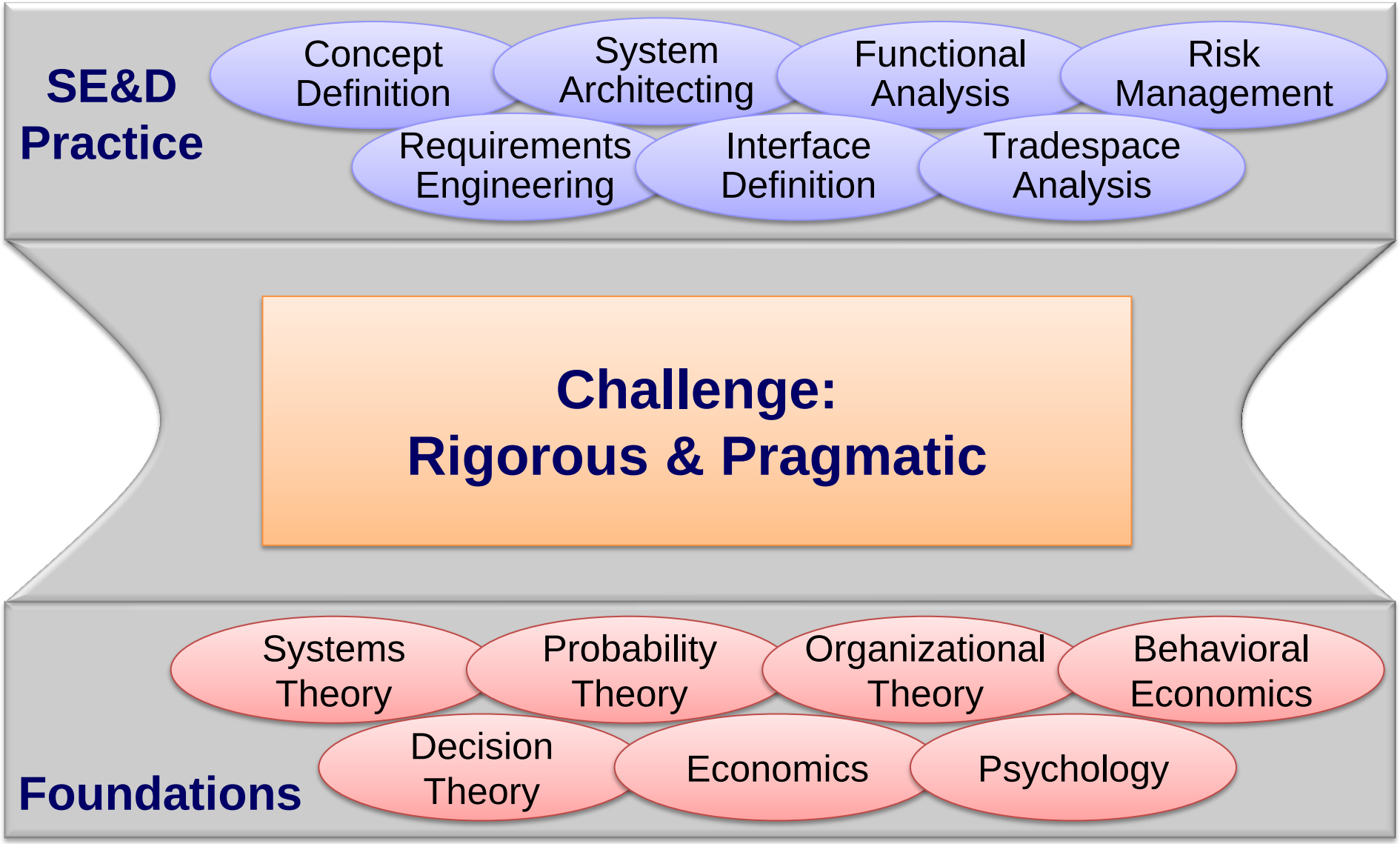

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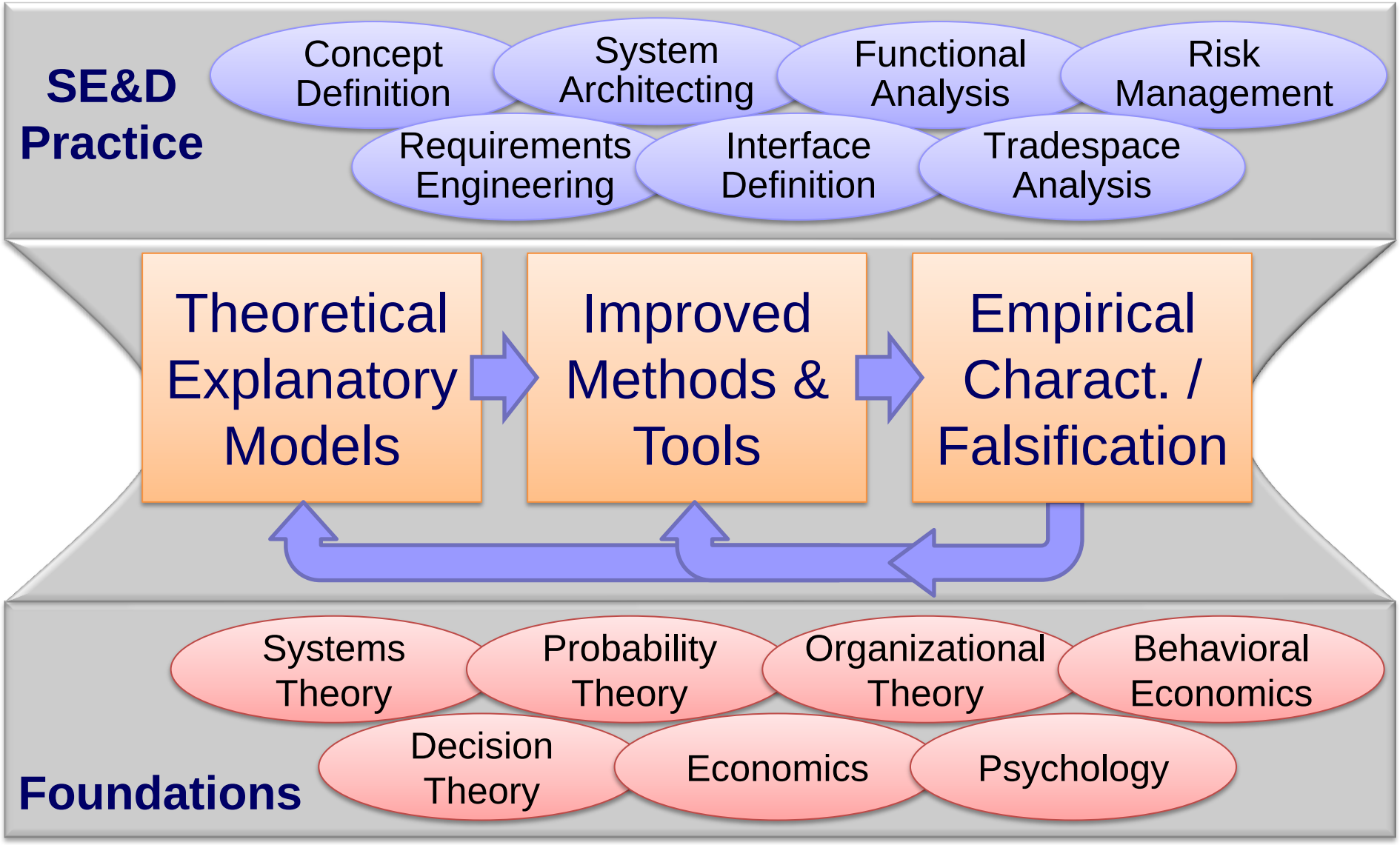

Systems Science (SYS)

Program Overview

- Role of Program
  - Leadership in grounding systems engineering and design practice on a rigorous theoretical foundation
- Focus
  - Theoretical foundation of systems engineering & design
  - Application domain independent
  - Special emphasis on Complex Engineered Systems
  - Draw on or extend established theory in mathematics, economics, organizational theory, social psychology, and other relevant fields
  - Empirical research is in scope when characterizing a theoretical model

→ An integrative scientific approach to support the development of complex engineered systems

Systems Science (SYS)

Some Research Examples

- Knowledge Representation
  - How can design knowledge best be captured and represented formally?
- Ideation and Cognition
  - How should tacit knowledge be elicited, expressed and incorporated in engineering ideation and decision making?
  - Which social and psychological processes are most important to successfully identify the outcomes of a particular design alternative, from a holistic, systems-thinking perspective?
- Uncertainty and Prediction
  - How should one quantify and manage uncertainty from initial engineering design predictions through to operation and maintenance of large scale systems?
- Engineering Decision Making
  - How should decisions be framed and sequenced to search a design space efficiently and effectively?
- Engineering Organizations
  - What is the relation of the structure of an engineering organization to design outcomes?

Systems Science (SYS)

Future Directions

- Processes: Search Strategy, Guidance and Control
  - Design as a search process → What are good search strategies? Appropriate abstractions? Metrics for process control? Influence of uncertainty?
- Organizations: Decomposition, Communication and Incentivisation
  - How to decompose problems and delegate the decomposed parts? Impact of incentive structures? How to facilitate communication between experts with disparate backgrounds towards ideation and analysis in design?
- Modeling: Creation, Use and Assessment of Models
  - Which modeling formalisms are most appropriate when? What are the cognitive models of modeling? How best to teach modeling? How to facilitate reuse and sharing? How to assess and characterize the accuracy and applicability of models?
- Research Methodology
  - We want to "improve" design, but we don't agree on what "good" means or how to assess "goodness"

  → Given that the theoretical foundations need to be operationalized into pragmatic, domain-specific methods and tools that are based on approximations of the foundations, how can we efficiently and effectively derive such methods and tools, and characterize their performance and applicability?

Where do SYS and ESD fit in?

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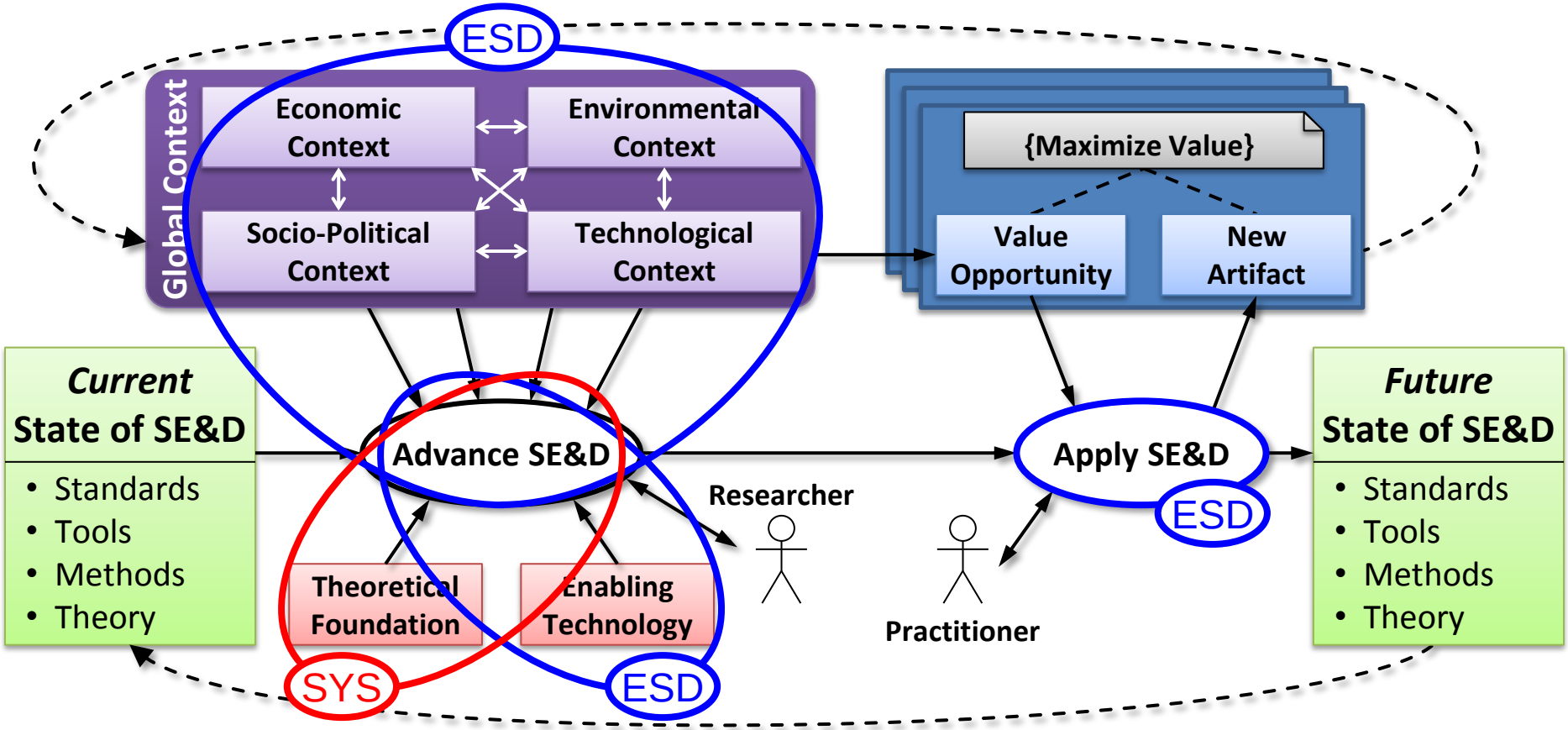

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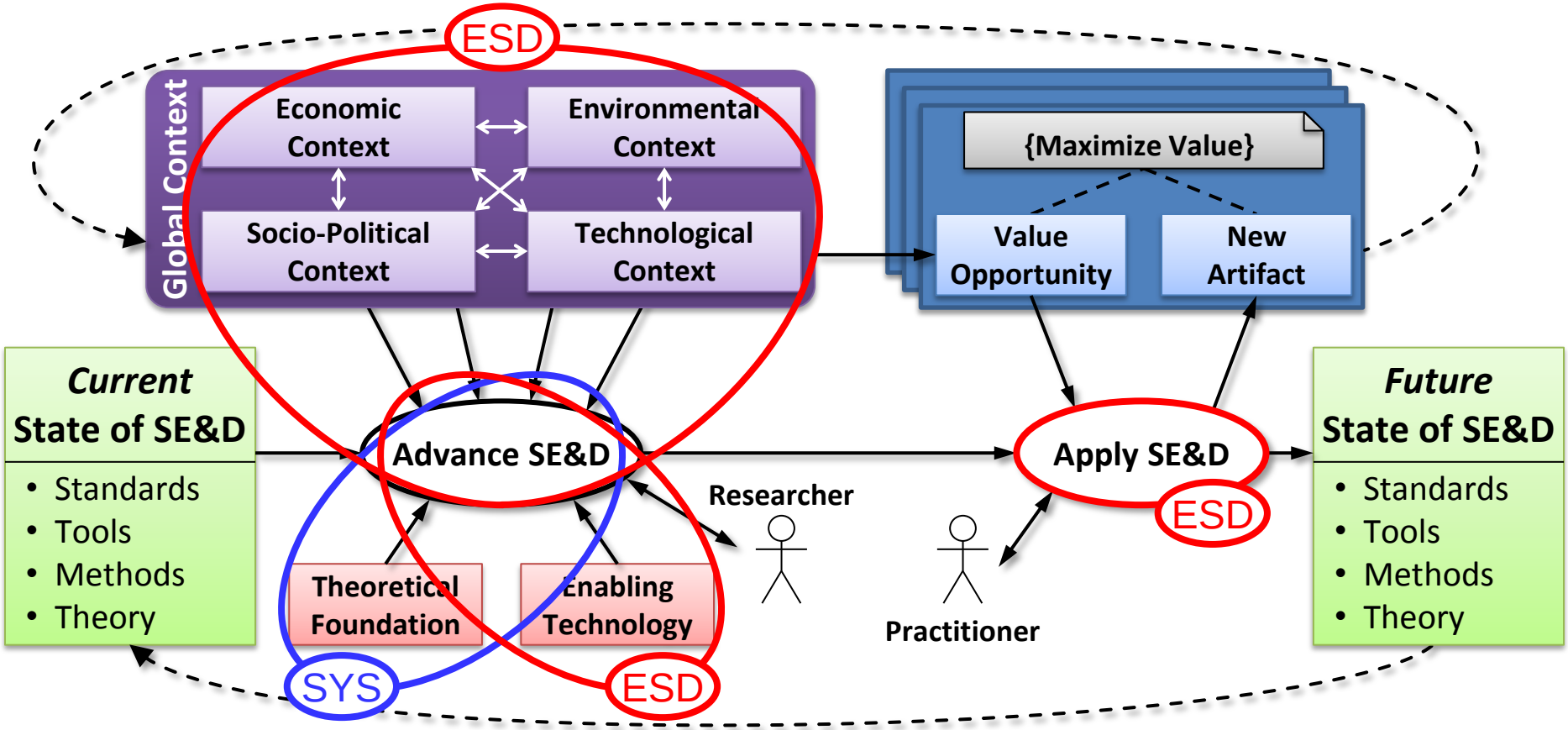
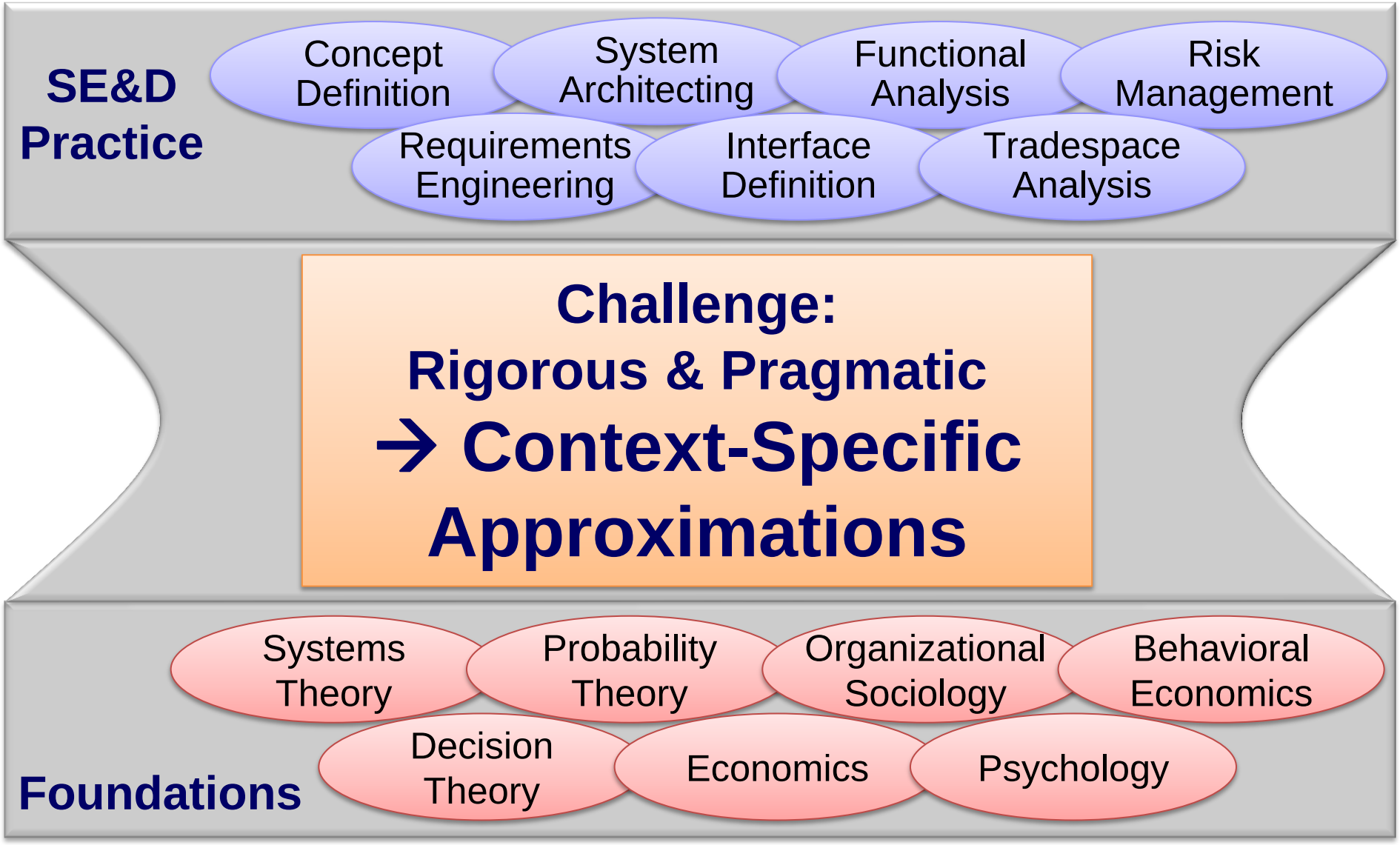


Engineering & Systems Design (ESD)

Building on the Theoretical Foundation



Engineering & Systems Design (ESD)

SE&D Methods & Tools for a Specific Context

- As the context changes, SE&D must adapt…

…by operationalizing the theoretical foundation for each specific context

- Increasing complexity
- Shorter lifecycle times
- Decentralization
- Systems of Systems
- Mass-customization
- Human-centered

- Cloud-based high-performance computing
- Big data
- Immersive data visualization
- Net-enabled collaboration

Engineering & Systems Design (ESD)

SE&D Methods & Tools for a Specific Context

- As the context changes, SE&D must adapt…

…by operationalizing the theoretical foundation for each specific context

A new context implies new approximations:

- Synthesis heuristics — which architecture patterns?
- Analysis idealizations — which formalisms, fidelity?
- SE&D process heuristics — when to do what?
- Organizational structure — who does what?

- In
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- Systems of Systems
- Mass-customization
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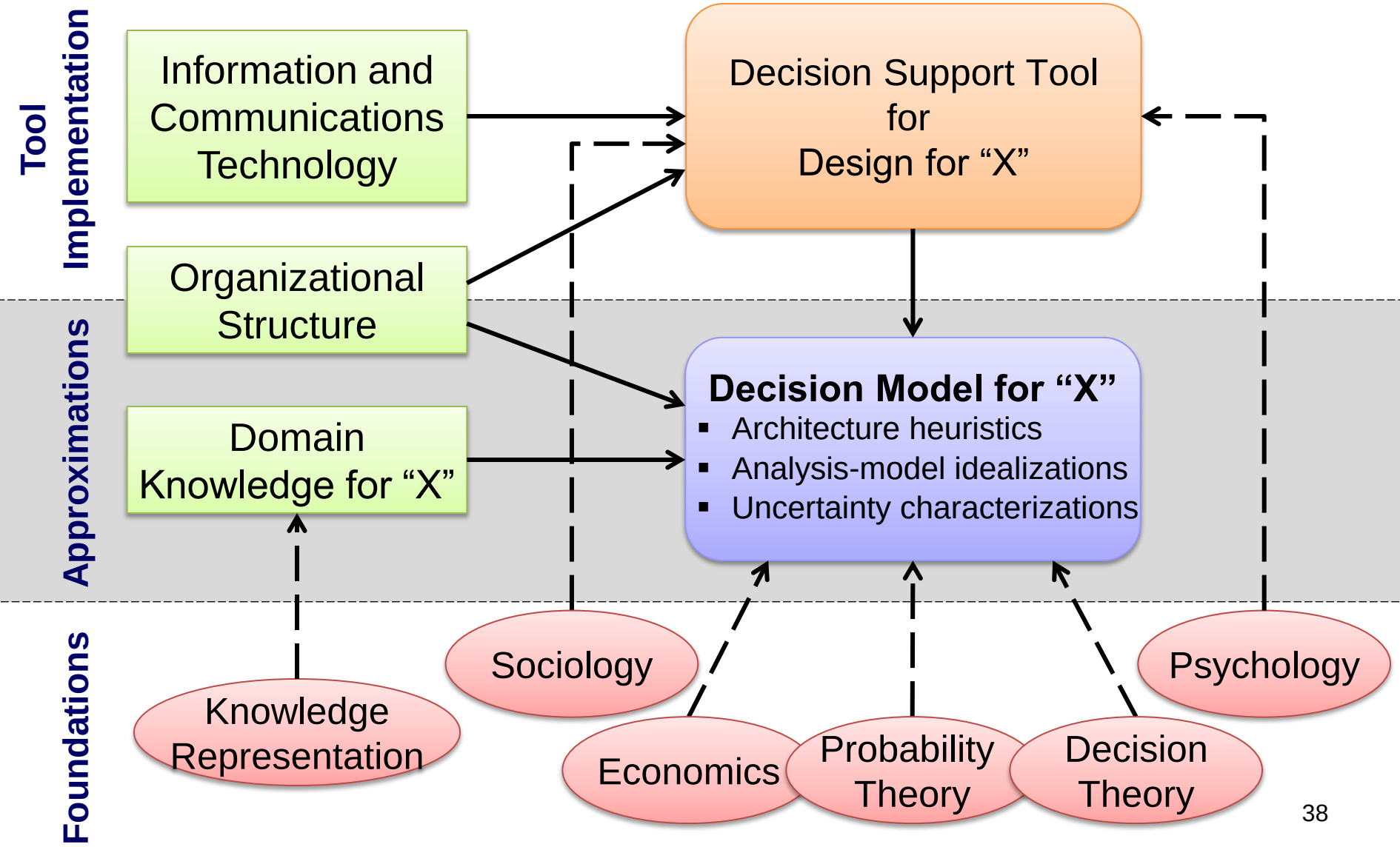
Engineering & Systems Design (ESD)

An Illustrative Example



Engineering & Systems Design (ESD)

Program Overview

- Role of Program
  - Leadership in advancing engineering and systems design practices for current and future global contexts, by combining rigor and pragmatism
- Program Focus
  - Operationalizing the theoretical foundation in specific contexts
    - » Develop pragmatic methods to apply the theory efficiently and effectively in a specific economic, socio-political, environmental and technological context
  - Rigorously characterizing current and novel methods
    - » In which context and under which assumptions is a method effective?
    - » Rigorously gather theoretical and empirical evidence, regarding current and improved practices
  - Education
    - » Develop effective teaching strategies rigorously based on cognitive models

Engineering & Systems Design (ESD)

Future Research Directions

- Design for X
  - *X = Specific Application Domain* — energy systems, consumer products, additive mfg,…
  - *X = Specific Concern* — resilience, sustainability, usability, manufacturability, …
- Novel Information and Communication Technologies in SE&D
  - immersive visualization and human-computer interaction, social networking and net-enabled collaboration, modeling frameworks and languages, data mining and analytics, high-performance computing and cloud-computing
- Novel Modeling Formalisms & Algorithms
  - Formalisms and algorithms for representing and manipulating form, function and behavior; algorithms for analysis, simulation, optimization, or reasoning; algorithms for prediction, uncertainty quantification and propagation
- Novel Integrated Frameworks for SE&D
  - Frameworks combining concept generation, gradual specification refinement, models at different abstractions, uncertainty characterization, optimization, human input, HPC, visualization, … to achieve efficient and effective search.

→ We Need to Rigorously Characterize and Assess Domain-Specific Methods

Program Opportunities & Logistics

What you need to know to submit your proposal?

- Unsolicited proposals submission windows
  - Fall: September 1-15
  - Spring: February 1-15
- Typical scope of proposals: 1-2 PIs, 1-2 PhD students, 3 yrs
- CAREER – proposals accepted for both SYS and ESD
  - Deadline: sometime mid-July 2015
  - Solicitation number: NSF 14-532 → to be updated for 2015
  - Budget: $500,000
- Interested in being a panelist?
  - E-mail me a 1-page description of your background & interests
- More info at:
  - ESD: https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13340
  - SYS: https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504788

Related Programs

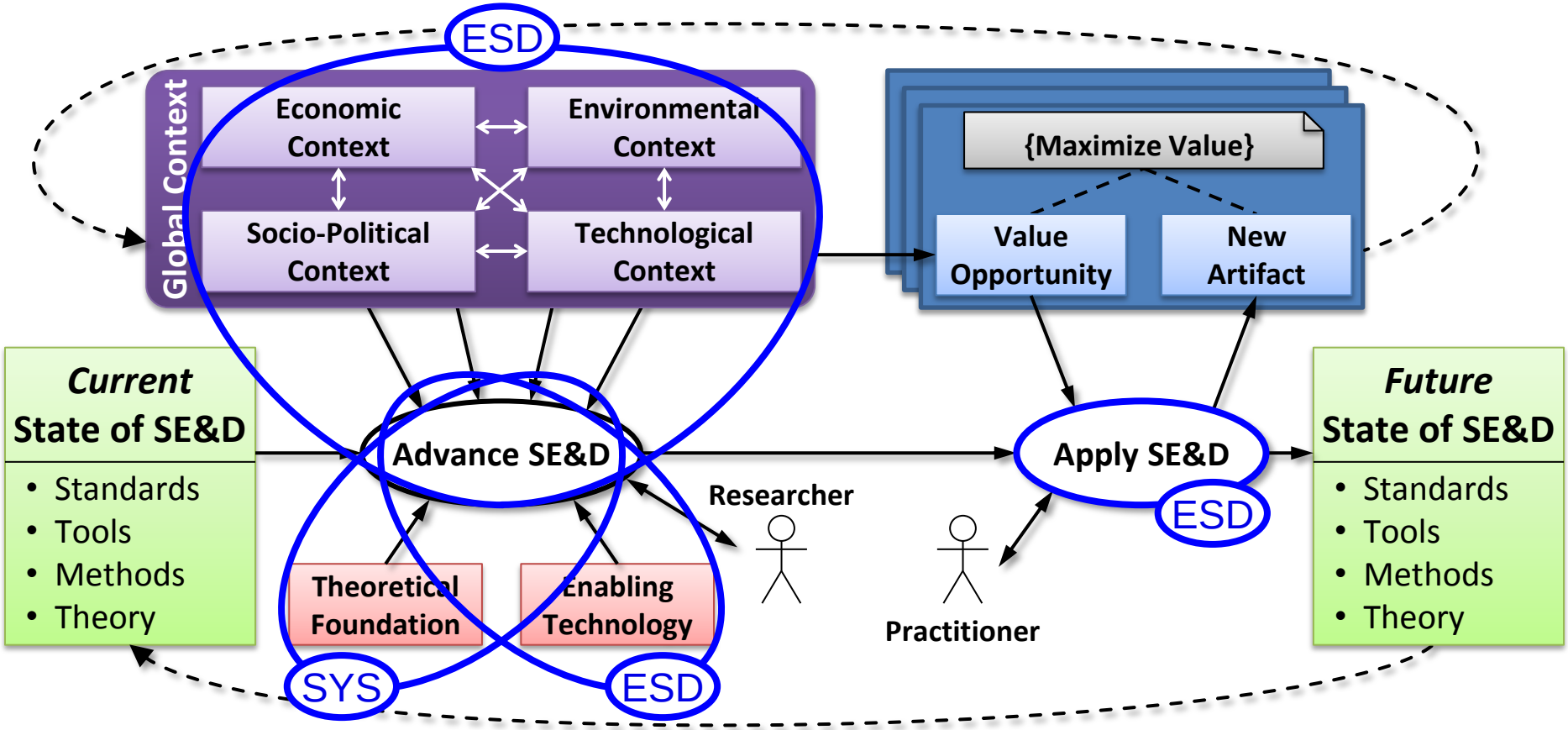
How can you expand your funding base?

- GOALI: Grant Opportunities for Academic Liaison with Industry
- DEMS: Design of Engineering Material Systems
- RSB: Decision Frameworks for Multi-Hazard Resilient and Sustainable Buildings
- CPS: Cyber-Physical Systems
- ACI: Advanced Cyberinfrastructure
- CDS&E: Computational and Data-Enabled Science and Engineering
- INSPIRE: see NSF 14-106. We will specifically consider proposals that tie SE&D to organizational sociology or cognitive science — other interdisciplinary topics will be considered also.

- Additional opportunities will follow… Subscribe to NSF News

Summary

Advancing the State of Knowledge in Systems Engineering and Design



Some References & Introductory Material

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